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RAMMED
EARTH WALLS
FOR BUILDINGS



EARTH has been used for building dwellings from time immemorial. One method of use, superior to others, and which was known to the Romans, has been preserved by tradition to modern times.

This method consists of ramming slightly moist, specially selected earth, without the addition of straw or other material, between movable forms, and is known by its French name, "pisé de terre," which means "rammed earth."

Pisé de terre is a reliable building material when properly handled and is admirably adapted to structures on farms distant from transport routes.

Little information has been published on rammed earth in the United States. The contents of this bulletin were abstracted chiefly from accounts of experimental work in England.

Washington, D. C.

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RAMMED EARTH WALLS FOR BUILDINGS

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CONTENTS

Page		Page	
Introduction		Construction—Continued.	
Pisé de terre	1	Openings in walls	14
Selection of material	1	Lintels and sills	15
Test for quality and consistency	3	Chimneys and fireplaces	16
Preparation of earth	4	Plates for joists and rafters	17
Tools and forms	5	Partitions	17
Wall thickness	6	Interior wall surfaces	18
Foundations	7	Exterior wall surfaces	19
Construction	8	Cost of pisé work	20
Placing and ramming	9	Protection from animals and ants	20
Bonding	9	Blocks	21
Reinforcement	11	Use of contractor's implements	21
Support of joists	13	Conclusion	21

INTRODUCTION

EARTH HAS BEEN EMPLOYED in the building of houses by nearly every people whose history is recorded. Savages construct dwellings by daubing mud on a framework of reeds or small branches. Early settlers in the Middle West built the walls of their homes by piling up successive layers of matted sod.

These methods produce only crude structures, but there are two methods adapted to pretentious and permanent buildings. The first and better method is known as rammed earth or pisé de terre and is the subject of this bulletin. The other method is the adobe construction of the Southwest, which is built in practically the same way in England under the name of "cob." Adobe or cob consists of a mixture of suitable clay, sand, and fiber, which may be grass and roots in the sod or straw. The mixture is puddled and laid on the wall and, before it has become too hard, is trimmed true to line. Sometimes it is cast into bricks. Many old and handsome buildings in the Southwest and Mexico bear evidence of the durability of adobe in a semiarid climate.

PISÉ DE TERRE

Pisé de terre (pronounced pee-zay duh taire), the French for "rammed earth," is an ancient type of construction. The writings of Pliny state that watch towers of this material constructed by Hannibal were in use 250 years after completion. It was introduced into France by the Romans and later was adopted in England. There are a few examples in this country. One in Washington, D. C., is said to be more than 150 years old (fig. 1) and another (fig. 2) is of recent construction.

¹ Deceased, 1936.

Pisé de terre walls are built by the simple process of ramming selected earth containing a suitable amount of moisture between wooden forms, which on drying out becomes surprisingly hard and durable. Forms can be removed as soon as the earth is compacted. Rammed earth must be protected from water, and foundations, exterior surfaces, and openings in walls must be designed to prevent damage from this cause. Summer is the best time to build, but it can be done at any season that is dry with no probability of severe frost.

Modern experience has developed practically no information unknown to earlier users, but it has confirmed old evidence that rammed earth is superior to some building materials commonly employed at the present time.

This type of construction is especially appropriate for rural structures in districts remote from railroads where building materials



FIG. 1.—A house now standing in Washington, D. C., the main portion of which was built of rammed earth in 1773. The portico and rooms at rear have been added in recent years.

are not easily procurable. In general, suitable earth is readily obtainable, and a farmer who lacks capital can as the result of his own labor produce cheap, attractive, and durable structures, the walls of which provide dryness and insulation against heat and cold. The services of skilled artisans are not required, because pisé work presents so little difficulty that it can be done by anyone without previous experience who will exercise care in a few particulars.

Though commonly confined to one and two story buildings (fig. 3), pisé walls have been carried to a greater height, as in the instance of a church in France which was 80 feet long and 40 feet wide, with walls 18 inches thick and 50 feet high. After standing 80 years the church was burned and the walls remained unprotected from the elements for a year before an attempt was made to tear them down.

They were so difficult to demolish that they were used in the restored church.

SELECTION OF MATERIAL

The most important considerations in pisé work are (1) the selection of a proper soil having the correct amount of moisture and (2) a thorough compacting of the earth. Success with this material is dependent upon other factors, but unless the earth is suitable and thoroughly rammed the structure will be a disappointment if not a failure.

The qualities the earth should possess are found in a surprisingly wide variety of soils yet all earths are not suitable.² Pure clays are



FIG. 2.—A house near Washington, D. C. The first-story walls are of rammed earth resting on a foundation of concrete blocks

not recommended because of excessive shrinkage, and pure sand will not bind. A mixture of the two, however, is good, especially if it contains small round gravel. A German author recommends a thorough mixture of 1 part stiff clay, 1 part sharp sand, and 2 parts stone broken to the size of a walnut.

Most ordinary earths are suitable or may be made so by admixture, but, according to most authors, all organic or other matter subject to rotting or slaking must be eliminated, hence top or vegetable soil should not be used.

² Specifications for Rammed-earth Construction, by R. L. Patty. *Agri. Engineering*, vol. 17, p. 476, 1936.

If the earth forms into clods when dug or if the sides of an excavation remain firm it is an indication that the soil may be fit for pisé de terre walls. The soil in a footpath which remains hard in wet weather is promising material. Earth in which wheels have formed ruts from which it is difficult to turn when dried out may be suitable. Difficulty in crushing a dry lump of soil between the fingers is another indication of suitability. Frequently the soil from cellars or trenches is fit for building or may be easily made so by mixing with other soils.

If an earth found on the proposed building site is not of the proper composition, it may possibly be made suitable by the addition of a small quantity of a different earth from another locality. The cost



FIG. 3.—An English example of two-story rammed-earth construction. (Courtesy of His Majesty's Stationery Office, London.)

of transporting suitable earth from a distance may, when other materials are locally available, render pisé construction uneconomical. If the earth is too sandy, then clay must be added, whereas if clay predominates, sand, gravel, or almost any mineral material will improve its quality.

TEST FOR QUALITY AND CONSISTENCY.

The variation in suitable earths, with respect to quality and consistency, is so great that the following test should be made before accepting or rejecting a soil:

A small wooden tub or pail, without a bottom, should be placed in a hole in the ground in the bottom of which a flat level stone or other

firm base has been set; the space around the tub should be filled with well-rammed earth, so that the tub is tightly inclosed to prevent its bursting. The earth to be tested should then be rammed into the tub, in layers 3 or 4 inches thick. When the tub is brimful any surplus earth should be scraped off, the earth packing loosened and the tub, containing the compressed earth, removed.

If, on inversion of the tub, the compressed earth will not come out it should be allowed to dry for 24 hours in the air, when it will have shrunk enough to permit the removal of the tub. The lump of earth should be covered to protect it from a direct shower of rain; an oblique shower falling on the sides should not mar it. The earth is fit for building if, upon continued exposure to the air, it continues, without cracking or crumbling, to increase daily in density and compactness as its natural moisture decreases.

PREPARATION OF EARTH

All top soil containing organic matter should be cast aside as unfit for use. The earth should be dug and if necessary sifted, so as to remove stone above the size of a walnut, and then piled in a large heap to keep it from drying out and to permit uniform distribution of moisture. It is a good plan to keep some earth under shelter so that a supply in proper condition will be always at hand. When a screen is not available, the large stones can be removed with a rake having teeth $1\frac{1}{4}$ inches apart; if the earth is thrown into a cone-shaped pile, the large stones will roll to the bottom. An earth of poor quality may be improved by mixing it in a pile with a more suitable soil, a shovelful of the better to five or six of the poorer or as the case demands.

Before it is placed in the wall the earth should be turned over with a shovel two or three times to assure uniformity, but only a sufficient quantity for two or three days' use should be prepared at one time. Three men can easily place 2 cubic yards of rammed wall per day. As the volume of the compressed soil is but little more than half of the loose soil, 4 cubic yards should be prepared for the day's work. In determining the availability of suitable earth the total quantity required should be estimated upon the same basis.

It is important that the soil have the proper moisture content when used. If put into the forms a little too moist the soil can not be properly compacted and a stroke in one place makes it rise in another. In such case it is best to stop work until the earth has dried sufficiently to permit proper ramming. There is not the same necessity to stop work when the soil is too dry, for it may be moistened to the proper degree by sprinkling with water and mixing well.

Generally, fresh earth contains sufficient moisture to insure proper consolidation. The tendency of the inexperienced is to work with too damp a soil. As long as the rammer will consolidate without pulverizing the material, it may be assumed to be wet enough. On account of the plasticity of wet earth, ramming is ineffective; the earth remains unconsolidated and will shrink and crack on drying out. In general it will be found that the moisture content should be between 7 and 14 per cent of the weight of the mixture. In British experiments a clay-gravel-sand mixture containing 15 per cent of

water gave the best results, whereas a chalk-loam mixture worked best with only 7 per cent water.

The percentage of moisture can be found by weighing samples of earth when moist and again when dry, the difference in weight, taken as a percentage of the dry weight, giving the figure required.

The following simple procedure will enable one to familiarize himself with the "feel" of earth containing approximately the right amount of moisture, or about 12 per cent. Sift about 12 pounds of the earth into a pan and dry it thoroughly in an oven, stirring the earth occasionally to hasten the process. Place 8 pounds of the dried earth in a flower pot or similar container having a hole in the bottom. If the pot is placed in a pan containing 1 pound of water the earth, through capillary attraction, will absorb all of the water and the soil thus uniformly moistened will be of about the right consistency for ramming. A handful of the soil, compacted by squeezing, should break apart when dropped to the ground.

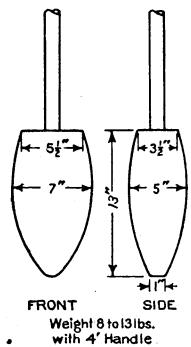


FIG. 4.—Pisoir made of hardwood root

TOOLS AND FORMS

The only special equipment comprises rammers and forms. These are simple and can be made by anyone handy with ordinary tools. Of course, picks, shovels, wheelbarrows, screens, buckets, barrels, and watering pots are required in proportion to the magnitude of the work.

According to early writers, three rammers were required, one being of heart shape somewhat like that shown in Figure 4, which is an illustration of an old type. It was thought that success in this work depended upon the use of this type, or some modification of it, the reason advanced being that the wedge-shaped head compressed the earth in four directions and tended to knit it together, whereas a flat-faced rammer formed a crust that prevented the consolidation of the lower earth. The flat-faced types, however, permit of thorough ramming along the edges and in the corners of the forms. The head of the rammer, the surface of which should be smooth, should be made of metal or the root of some hardwood tree. Several types of rammers, as used in early work, are illustrated in Figure 5. Opinion varies with respect to the use of the heart or wedge-shaped rammer. Some recent workers in pisé, together with early writers on the subject, claim its use essential to best results yet others have attained apparently excellent results with the use of only flat-faced rammers. Two cast-iron and one metal-faced wood rammer, used in erecting the walls of the house shown in Figure 2, are illustrated in Figure 6.³

The forms now used differ little from those described by the earliest authors. The general requirements of a form are that it should be reasonably light, easy to handle, very rigid, low in cost, and not liable to warp. It should be adjustable to different thicknesses of walls, easily disengaged from the walls, one side at a time,

³ These rammers were made in accordance with directions furnished by P. B. Aird, Agricultural College, Natal, South Africa.

and should afford means of blocking off the earth at openings or wherever desirable. Figure 7 is a suggestion for a form that is simple in construction and operation. The corner form can be adjusted to different wall thicknesses by using the proper width of filler pieces and moving the exterior corner battens and clamps to suit. The length of the tie bolts, which should be threaded at both ends, will vary with the thickness of the earth wall. The use of tail nuts having a 3 or 4 inch lever arm obviates the necessity of a wrench and will facilitate the work. Pieces of old wagon tires could be used instead of bolts if holes were punched for pins or wedges. A series of holes spaced an inch apart at ends of the pieces of tire would admit of their use in building different thicknesses of walls.

Although a special corner mold is not essential, it is a convenience. The number of form sections required will depend upon the number of workmen available and the rate at which the work is to be done. Two are necessary, even though both are designed as straight-wall forms, because when the corners are built cleats must be put on the inside at one end of one of the sections to hold a head or end board. The cleats must be put on very securely to withstand the pressure due to the ramming, and if they are removed every time the section is used in the straight wall—that is, without the end board—and replaced when it is used to form corners, the fastenings will wear out in a short while; moreover, the changing would cause considerable delay in the work. At the end of the form used at corners the bottom boards must be cut away a depth of 6 inches and a length equal to the thickness of the earth wall, to permit the form when set up at a corner to extend over the intersecting wall and at the same time grip the wall being built as in Figure 8. Both the inside and outside of the form are cut in this manner, so that it will fit on either end of the wall.

Difficulty is encountered at times in withdrawing the bolts from the walls. A possible method of overcoming the difficulty is to place a thin layer of fine, dry sand around each bolt as the earth is rammed into the form. The sand should keep the bolt from binding and could be easily poked out after the bolt is withdrawn. The practice followed in concrete construction of greasing the bolt or wrapping with heavy paper might be feasible, but so far as known has not been tried in pise work.

WALL THICKNESS

The required thickness of walls has not been determined by tests, but it is customary to make the first-story walls 18 inches thick, the second story walls 14 inches, and the interior bearing partitions 12

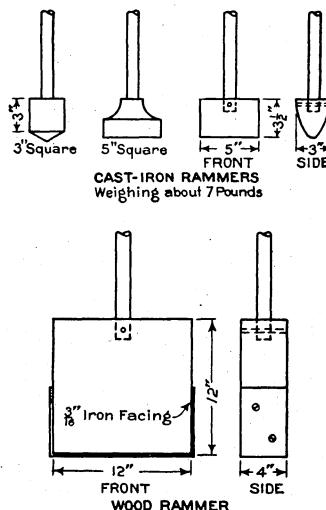


FIG. 5.—Metal and wood rammers

to 14 inches. Where room space is limited and there are many partitions, they are usually made of some other material. A German writer recommends that, in general, pisé walls should be from one and one-half to two times the thickness required for brick walls. Walls of one-story outbuildings which are not subjected to heavy loads might well be made 12 or 14 inches thick.

FOUNDATIONS

Foundations and all walls in contact with earth must be of concrete or other masonry. The footings should be below frost line to prevent heaving, and the masonry should be carried up at least 12

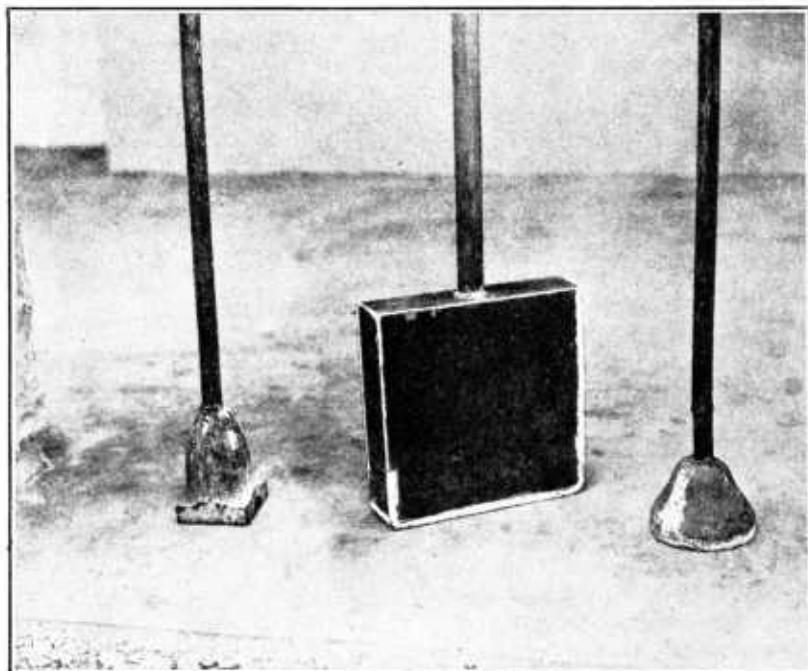


FIG. 6.—Rammers used in the construction of the house shown in Figure 2. (Courtesy of H. B. Humphrey.)

inches above the surface of the ground, so that rain will not splash on the earth walls. The foundation must be of the same thickness as the superstructure, generally 18 inches, and there should be a damp-proof course on top of it to prevent moisture from rising by capillary attraction into the rammed earth. A course of slate embedded in mortar, made of one part Portland cement and one part sand, forms a very effective barrier against moisture, but the slate should be protected with two courses of brickwork on top to shield it from damage while the earth is being rammed. Several thicknesses of tar paper bedded in hot tar forms a good damp-proof course.

Foundations of earth, rammed into a trench 6 inches wider than the upper wall and with a damp-proof course at the ground level,

have been used in South Africa. It is said that so long as running water is kept from contact with the base of the walls there has been no detrimental effect. Such foundations might be employed where there is no frost action and where the subsurface conditions are known to be otherwise favorable. In the light of present knowledge it would not be wise to erect a permanent building, especially one in which human beings or valuable stock are to be housed, on foundations of rammed earth.

CONSTRUCTION

PLACING AND RAMMING

When the foundation has been completed, the form is set up at one corner overlapping the masonry 6 inches. A workman should

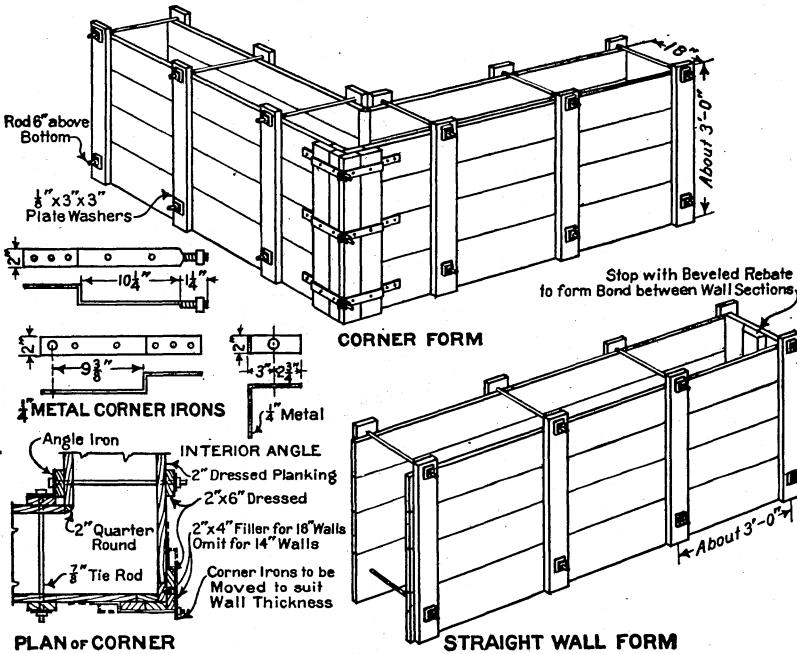


FIG. 7.—Corner and straight-wall forms

be placed in each division of the form, the most skillful being placed in the corner. He should direct the work of the others and see that the form does not swerve from line or level; this is very important at the start of each setup, because when the form is half full it can be adjusted only with the greatest difficulty.

The earth is shoveled into the forms in 4 or 5 inch layers, the men in the form spreading it evenly. The earth in the corners and close to the sides of the form should be rammed first and then the rest of the surface. The strokes should cross one another so as to press the earth in all directions and knit it together which, according to some authorities, is best accomplished with a wedge shaped rammer. This also leaves the surface somewhat rough, providing a key for the succeeding course. The ramming should be rapid and

equable and should not be in unison; that is, the men must not keep time in striking the earth nor are heavy blows desirable. Care must be taken that no fresh earth is received into the form until the previous layer is well beaten, a condition evidenced by a ringing sound at each rammer stroke. Layer after layer is rammed hard until the form is full and level with the top unless the end of the section is to be sloped to provide for bonding as described later. The form then can be taken apart and reset.

After each course of the walls is completed the forms are set up for the next course in such a way that the work progresses in the opposite direction in order to provide a bond. Before any earth is put into the forms, the top of the lower course should be roughened, brushed free of loose particles, and slightly moistened so that the fresh earth will adhere to the drier earth already in place. Thus,

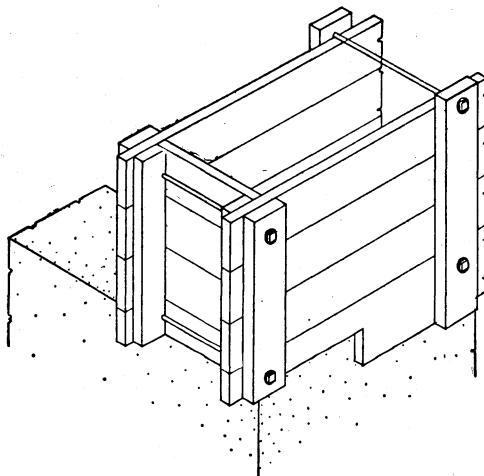


FIG. 8.—Straight-wall form for use at corners

nailings for a stair carriage. Not being fully embedded in the pisé wood inserts should be creosoted or otherwise treated to prevent decay.

Sharp exterior corners in earth walls are chipped easily, and it is therefore customary to round off the main corners to about a 9-inch radius. This can be done by placing a fillet or length of cove molding in the corner of the form, as shown in Figure 10, or the sharp edges can be rounded, after the ramming of the walls is completed, by scraping, but this method is a little troublesome.

The bolt holes generally are not filled until all the earth work is completed. They are useful in supporting a scaffold when the outside surface of the walls is to be stuccoed or otherwise treated. They are finally filled with earth rammed flush with the surface of the wall.

The top of the wall should be protected from rain, as too much moisture might cause a serious weakness in the structure.

section by section and course by course the walls are raised to the desired height, care being taken to provide for openings, plugs, anchors, etc., at proper locations; although an opening can be cut or a hole drilled after the earth hardens, it is done only with difficulty because the pisé becomes almost as solid as concrete.

Wood plugs and blocks must be inserted in the earth walls as the work progresses, as in masonry construction, for securing frames and trim to the walls. (See fig. 9.) The two blocks at the right are

BONDING

Special precaution must be taken to bond adjoining sections in the various courses. One method is to slope the earth at 45° in that end of the form adjacent to the section next to be built. A good bonding joint which may be more easily formed is made by using, in this end of the form, a bulkhead to which a 2 by 4 inch or 2 by 6 inch piece is fastened, as in Figure 11, so that a rebate will be molded in the earth. A wall in course of construction using this method of bonding is shown in Figure 12. The joints in each successive course should not come directly over those in the preceding course, but should break bond as in masonry. Where sloping joints are used the slant in each course should be opposite to that in the joints of the previous course. (Fig. 13.)

At the corners a special corner form is used or a straight form as illustrated in Figure 8. With the straight form each course is placed in the direction opposite to that of the preceding, and quoins are formed at the corners as illustrated in Figure 13, effecting good bond.

REINFORCEMENT

Old descriptions of pisé construction indicate the occasional use of reinforcement at outer corners and the junction of partitions with exterior walls. When the earth was not of a very good quality, a little was used in the walls. The reinforcement consisted of rough boards 1 inch thick, 8 to 10 inches wide, and 5 or 6 feet long, laid flat between the courses so as to cross at the corners. In the straight runs of wall, pieces of boards 10 or 11 inches in length were placed flat crosswise of the wall about 2 feet apart and were set in the pisé after the form was about half full; these short boards served to equalize the pressure of the upper parts of the walls on the lower parts. Wood embedded in earth should be creosoted.⁴

Reinforcement was not universally used in former times and modern construction seems to ignore it. Under average conditions

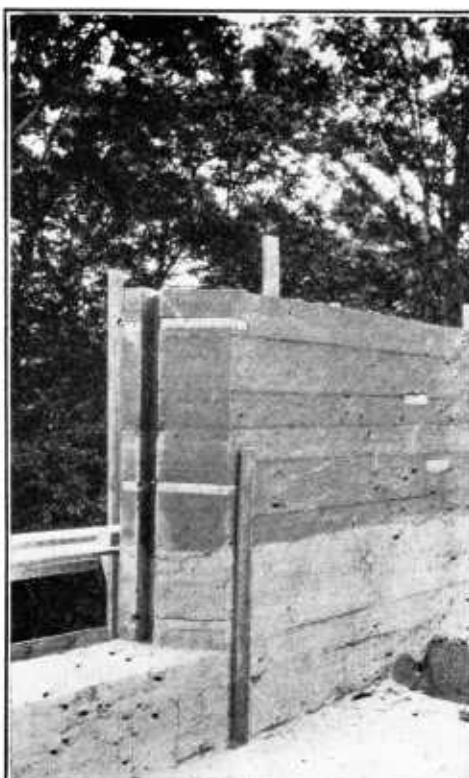


FIG. 9.—A window opening showing recess for weight box and embedded blocks to which the trim is nailed. (Courtesy of H. B. Humphrey.)

⁴ Farmers' Bulletin 744, The Preservative Treatment of Farm Timbers, contains practical directions for creosoting ends of joists, etc., that are to be embedded in walls.

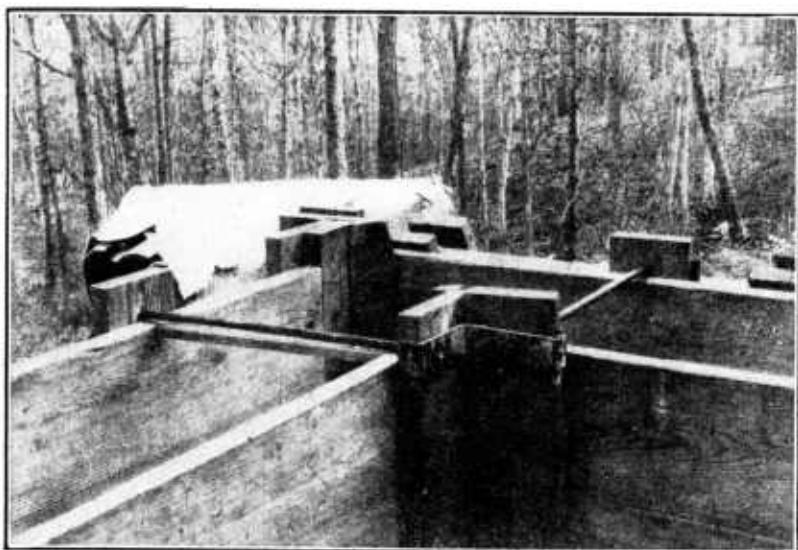


FIG. 10.—A form with coved insert to produce a rounded exterior corner. (Courtesy of H. B. Humphrey.)

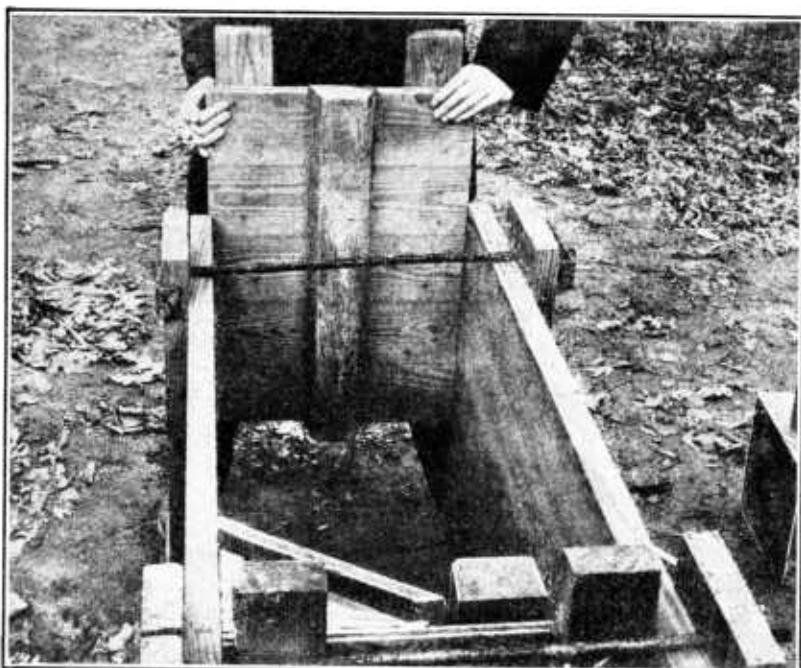


FIG. 11.—A straight-wall form with end stop or bulkhead and stop for window jamb. (Courtesy of H. B. Humphrey.)

it would seem to be unnecessary. However should a little reinforcement seem desirable in narrow pilasters between windows or at the junction of a partition and wall, metal lath or scrap iron can be substituted for the wood.

SUPPORT OF JOISTS

There are several methods of providing for the support of the first-floor joists. Blocks can be set in the form so as to make recesses to receive the ends of the joists in the masonry foundation or the earth wall (fig. 14), depending upon the relation of the floor level to the top of the foundation. If the joists are to rest in the foundation below the damp course, the recesses should be a little wider than the thickness of the joists, so as to permit of a circulation of air about the ends of the joists. Another method of forming the recesses is to fill the form to a level 6 inches above the level of the tops of the joists. With the form removed, recesses are cut in the earth with a chisel, the ends of the floor

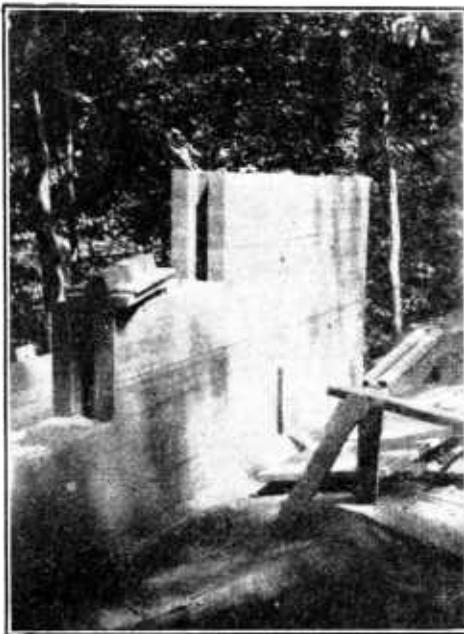


FIG. 12.—Three layers of rammed-earth wall, showing how adjacent sections are bonded. (Courtesy of H. B. Humphrey.)

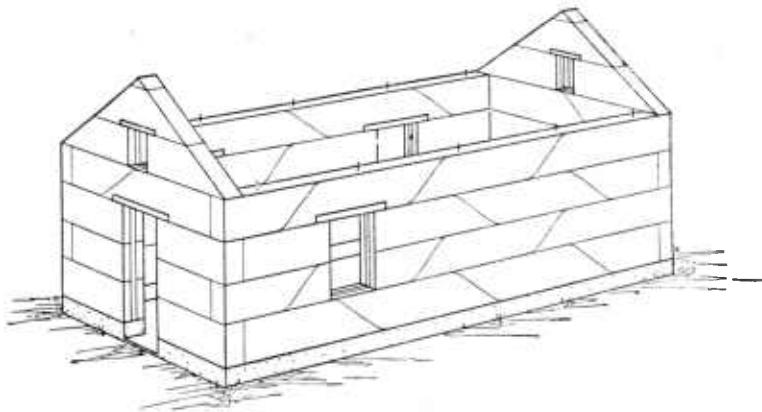


FIG. 13.—Method of bonding adjacent sections of earth wall

joists are inserted in the recesses, the form is reset on top of the joists and the ramming resumed. It is best to embed a wood plate 2 inches thick level in the wall as a bearing for the joists. Still

another method is to form a ledge by building out the foundation above the damp course, or by bolting a timber to the wall. (Fig. 15.)

OPENINGS IN WALLS

When there is no cellar, openings in the walls should be provided for ventilating the space under the floor. Such openings, which should be screened against mice and insects, can be made by setting tile in the forms.

Stops or bulkheads must be set in the forms at door, window, and other openings. They should be very securely braced to withstand the severe pressure created by ramming. (Fig. 11.) Before starting on the work, details of frames, sills, lintels, etc., must be definitely decided upon, so that provision can be made for incorporating or inserting them in the wall. The method of handling the

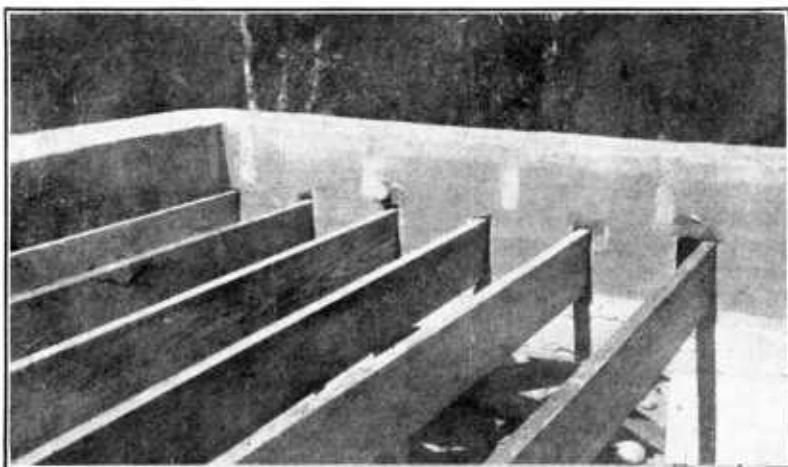


FIG. 14.—First-story joists resting on foundation wall. The wood inserts above the joists provide nailing for skirting. (Courtesy of H. B. Humphrey.)

forms should be predetermined to facilitate the placing of those members which project beyond the face of the wall, since they can not be set inside of the form and incorporated with the wall when the earth is being rammed.

Projecting members may be set after the wall form is removed, the wall being cut out to receive them; but the better method is to carry the wall up to a level 6 inches above the projection, the earth being omitted in the space to be occupied by the member. An extra depth of one-half inch should be allowed for bedding the sill, lintel, or molding in cement mortar after the form has been removed. The form is then reset on top of the inserted sill or other projection gripping the 6 inches of wall above it. In providing for a window sill which extends but 2 inches into the earth beyond the jamb, the stop or bulkhead may be set on line with the jamb, the rammed earth being cut or chiseled out later to receive the projecting ends.

LINTELS AND SILLS

The thickness of earth walls necessitates suitably designed lintels. If the jambs are of pisé, the lintels should bear on the wall at least 9 inches, and when the lintel is built up of several timbers a block should be bedded in the earth as a saddle to distribute the weight from above and assure uniform bearing. (Fig. 16.)

The face of the lintel may be made flush with the finished wall surface, or, if the walls are to be coated with stucco or plaster, the lintel may be covered with the same material. In such case the lintel should be covered with wire mesh or metal lath to provide a key for the surface coating. If the exterior is to be coated with a thin wash, the width of the lintel should be equal to the thickness of the wall; but when the exterior is to be stuccoed and the lintel exposed, the width should be increased by the thickness of the stucco.

In the earlier pisé work lintels were of wood, either solid or built up of a number of 2 by 4 inch scantlings placed side by side, requiring a considerable quantity of timber. A built-up wood lintel, economical of lumber, is shown in Figure 16.

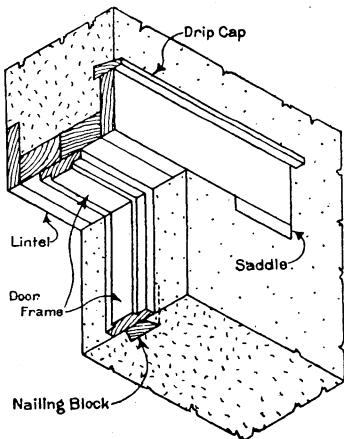


FIG. 16.—Detail of wood lintel and plank frame

For architectural effect a lintel should show a greater depth than 4 inches on the exposed face. This can be done by forming a lug on the slab, as shown by dotted lines in Figure 17. The bevel on the lug will to a great extent prevent water from the wall surface penetrating behind the lintel.

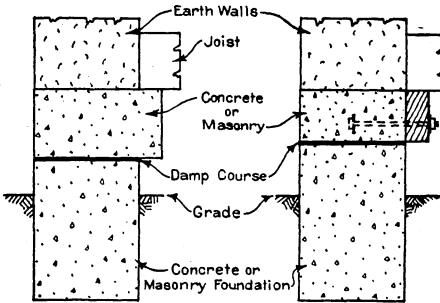


FIG. 15.—Method of supporting lower floor joists

The joint over wood lintels should be protected with a molded drip cap or one cut from a 2 by 4 inch scantling, the exposed or outer edge being five-eighths of an inch thick and the inner $1\frac{1}{8}$ inches. The cap should project from 1 to $1\frac{1}{2}$ inches beyond the finished-wall surface and should be 2 inches longer than the lintel. If the exterior wall is to be stuccoed, a rough lintel may be set flush with the earth wall and a dressed plank, the thickness of the stucco, secured to its face.

The simplest type of concrete lintel is a reinforced slab 4 inches thick, 18 to 24 inches longer than the opening, and of a width as determined by the thickness of the wall and any exterior coating.

Lintels and all inserts may be set in cement mortar, but when flush with the wall surface they are more frequently merely embedded in the earth as the wall is raised. Struts should be placed under lintels to relieve them of strain while the wall is being rammed.

Sills may be made of concrete, brick, or wood and should be 4 inches longer than the width of the opening. They should be pitched to shed water and should project 1 to $1\frac{1}{2}$ inches from the face of the wall. A sill detail is shown in Figure 18.

The treatment of the jambs should be decided upon before forming the openings. The external angles of earth jambs should be rounded. Frequently the openings are faced with brick or stone, forming a trim which often improves the appearance. Space for such masonry trim or facing should be provided by inserting blocks in the form during the construction of the earth wall. After the pisé has dried out the brick or stonework should be laid in mortar and secured with rust-resistant metal clips nailed into the earth walls, as in brick veneer over wood framing. If the masonry is built in as the walls are raised, the earth in drying will shrink away from it and settlement of the earth may cause a bulging of the masonry.

Because of the thickness of the earth walls, the interior jambs restrict the distribution of light from the opening and are therefore

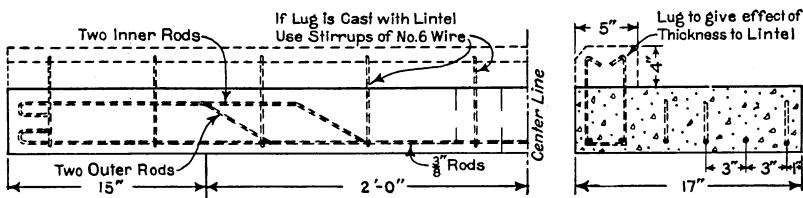


FIG. 17.—Reinforced concrete lintel

usually splayed or flared as in Figure 18. It is advisable to mold the openings for double-hung windows as shown in this figure, thus permitting the frame to be slipped in after the ramming is completed. In Figure 11 may be seen a window-jamb stop secured in the wall form. This arrangement provides for the setting of a double-hung frame by removing the weight boxes, inserting them in the slots left in the wall by the jamb stops, and then setting the frame, nailing the pulley stiles to the sides of the weight boxes. All door and window frames should be anchored to the wall. This can be done by nailing the frames to 2 by 4 inch blocks embedded in the rammed earth, as illustrated in Figures 16 and 18. After a door or window frame has been set, the joint between the earth and the wood should be filled with cement mortar or other packing. Figure 19 is a view of earth-wall construction showing door and window openings partially formed.

CHIMNEYS AND FIREPLACES

Generally chimneys and fireplaces are built of brick or stone. Attempts have been made to construct them of pisé, but so far it has not proven satisfactory. It is perhaps better to construct chimneys

and fireplaces of masonry⁵ as in ordinary house construction, bonding the earth and masonry as described above.

PLATES FOR JOISTS AND RAFTERS

Upper-story floor joists can be supported in slots cast in the wall or on plates resting on ledges formed by reducing the thickness of the walls. Details are suggested in Figure 20.

There is no difficulty in setting the plate for the roof rafters, as it can be secured by bolts set in the pisé. The bolts should be one-half inch in diameter, 15 inches long, and spaced 5 or 6 feet apart. The top of the wall should be damp proofed to prevent damage by water leaking through the roof. Figure 21 shows the arrangement of wall plate and waterproofing.

PARTITIONS

For interior partitions the use of some material other than pisé may be preferred, especially if the earth is inferior, making thick partitions advisable, or if the floor space is limited. Partitions from 9 to 12 inches thick have been made with good earth, and a particularly strong partition consists of rammed earth between studs spaced about 2 feet 6 inches apart. A triangular fillet or wood strip, nailed down the center of the studs, keys the earth to them, and boards clamped to the faces of the studs will serve as forms. Partitions should be bonded to the interior face of the exterior walls to eliminate settlement cracks. This may be effected by building the partition into a slot formed in the exterior wall when it is rammed. As ramming the earth of a partition against a completed exterior wall may damage the latter, temporary bracing against the exterior walls while the partitions are being built is at least on the side of caution.

Perhaps the best though most expensive method of bonding partitions to outside walls is the use of a special T-shaped form by means of which a short run of the partition is cast or rammed at the same

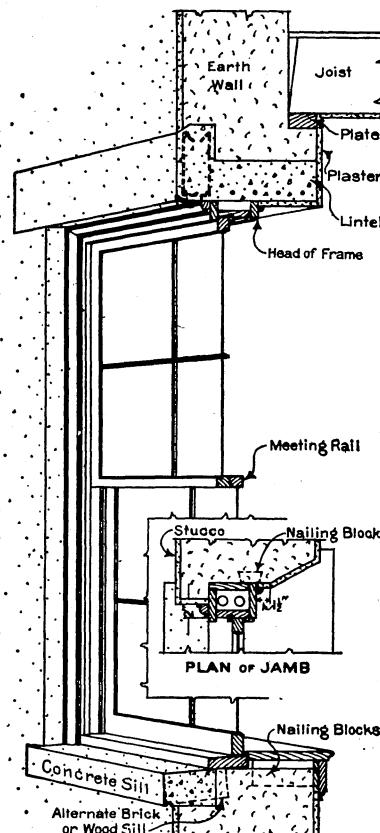


FIG. 18.—Details of double-hung window

⁵The Construction of Chimneys and Fireplaces, U. S. Dept. Agr. Farmers' Bulletin 1649, 1933.

time as the exterior wall. This is common practice and required when the inside walls support floor joists and necessitates the building up of the entire partition, course by course, with the outside walls.

INTERIOR WALL SURFACES

The walls must be thoroughly dry before any preservative or decorative treatment is applied. It is generally five or six weeks after erection before the walls are in proper condition for surface treatment. If plaster or other treatment is applied to an unseasoned wall it will probably fall off or loosen as the moisture evaporates from the rammed earth. When the walls are to be plastered or stuccoed they should be indented with a hatchet or scored with a rake to provide bonding for the coating. All loose particles and dust should be removed with a stiff brush. Just before the plaster or stucco coating is applied, the surface should be uniformly mois-



FIG. 19.—Rammed-earth walls under construction, showing partially formed openings. (Courtesy of H. B. Humphrey.)

tened to prevent the water in the mortar being absorbed by the earth; a thin mud wash containing a percentage of sand and called dagga plaster is sometimes used for this purpose.

The interior surfaces of unimportant structures may be merely whitewashed. If a somewhat better surface is desired, a thin mortar coat can be floated on the wall to fill up small voids or slight irregularities before the whitewash is applied. It has been said that wall paper may be applied directly to smooth earth walls which have been properly sized. The appearance of the finished wall will depend much upon the care taken to keep the forms true. The better class of houses should be plastered in the usual way. Furring strips and lath are not necessary as in masonry structures, since moisture will not condense on the earth walls, because of their insulating value. Ceilings must be plastered over lath, unless wall-board, wood, or other material is used.

EXTERIOR WALL SURFACES

The effect of rain beating against the natural surface of rammed earth walls is not so damaging as one might suppose. Pisé walls have stood several winters in England with no protection, and they have remained undamaged in India and South Africa through tropical downpours. It must be remembered, however, that in these latter countries the walls had been previously sunbaked to an extent beyond possibility in a temperate climate. It is generally admitted that some form of covering or finish is desirable, if not essential, in the better-class work where permanence is wanted.

Almost any treatment applied to earth walls will require repair. Inequality between the expansion and contraction of the earth wall and the covering is likely to cause cracks through which moisture will enter and eventually cause the coating to fall off in patches. Coatings that will not bond or stick to the wall are short lived, and materials which do not resist weather and wear are of little value.

So far, experience has not developed an ideal treatment. Experiments conducted by this Bureau, while not conclusive, indicate the short life of various kinds of brush coatings. Lime washes, cement washes, silicate of soda, Sylvester wash, lime-tallow coatings, and lime-casein washes showed poor penetration and practically no resistance to weathering and were not worth using.

Various preparations having a tar or asphaltic base were more promising. They form a bond by seeping into the earth walls. Of these, the Cunningham coal-tar paint,⁶ which is low in cost, adhered and resisted weathering fairly well. Linseed-oil paint was the most lasting of all brush coatings. Both lime and portland-cement stuccos of different mixtures applied without reinforcement failed to hold up.

The earth used in this particular experiment was not of the best type, being composed of 56 percent very fine material (the grain diameters

were less than 0.05 millimeter) classified as silt and clay. The surface produced was velvety and chalky, providing only a suction bond that was easily broken. Overhanging eaves, tight flashings, and drip grooves on window sills, were found absolutely necessary to keep moisture from getting between the wall and the coating.

⁶ Cunningham coal-tar paint: Stir 1 part of portland cement into 1 part of kerosene; then stir this mixture slowly and thoroughly into 4 parts of gas-house coal tar. Apply with a brush. The tar used is the liquid obtainable from gas plants and not the heavy pitch used for roofing and general waterproofing.

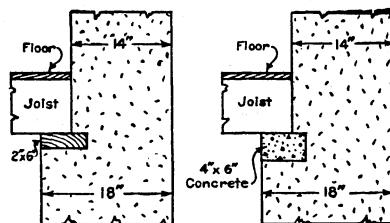


FIG. 20.—Method of supporting upper floor joists

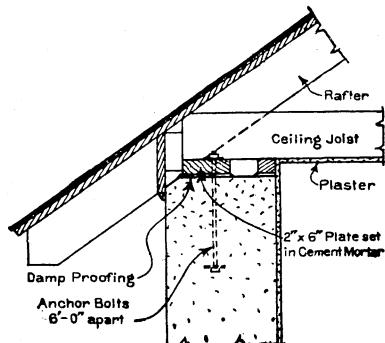


FIG. 21.—Detail of eave construction

From these results it would seem necessary, if periodic repairs are to be avoided, to veneer the outside with brick or stone slabs or to apply a standard stucco of cement or lime mortar over a lightweight metal lath. The lath should be securely fastened to the wall in the same manner as recommended for other types of masonry construction. It would also seem advisable to tar or otherwise waterproof the earth wall before applying the stone or brick veneer or the metal lath for stucco. The next best practice seems to be the use of two or three coats of outside linseed-oil paint.

Tar and asphaltic base preparations are effective when properly applied. A decorative paint is generally desirable to hide the black color, and experiments indicate that outside oil paints can be used if the tar base is first given a coating of aluminum or other flake metal floated in a good outside varnish.

The builder is referred to the recommendations of R. L. Patty, who has conducted extensive experiments to determine durable coverings for rammed earth walls. His findings are given in detail in Bulletins 277 and 298 of the South Dakota Agricultural Experiment Station, Brookings, S. Dak.

Directions for stuccoing and applying metal lath can usually be obtained from cement, lime, and hardware dealers or from associations interested in these materials.

COST OF PISÉ WORK

Builders differ in their reports as to the quantity of pisé de terre that can be placed in a day and also as to the cost. Although the cost depends upon a number of factors, as in other types of construction, the following may serve as a guide:

In England pisé dwelling-house walls 1 foot $10\frac{1}{2}$ inches thick were built 35 per cent cheaper than were 11-inch hollow brick walls in a similar structure. In another house there was a saving of 80 per cent in favor of pisé as compared with brick walls. In still another the pisé walls, 18 inches thick in the first story and 14 inches in the second, cost \$3.64 per square yard of surface as against \$5.07 for 11-inch hollow brick wall. The labor cost was 30 cents per hour. It should be borne in mind that any saving in cost resulting from the use of pisé is confined to the erection of the walls, as all other construction in two buildings otherwise alike would be practically the same.

As to the quantity of earth that can be placed in a day the following from an old report seems to be substantiated by recent experiments: Three men can place 54 square feet of 18-inch wall of the first story or 48 square feet of 14-inch wall of the second story in one day. Two of the men were employed in ramming and occasionally helping the third, who loaded a cart with the earth, hauled it a short distance, and then placed it in the forms.

PROTECTION FROM ANIMALS AND ANTS

Most earth walls are subject to attack by rats, but many builders claim that pisé de terre is so dense that the rats can not gnaw it and that it is free from such attacks, especially when a good masonry foundation is provided. However, in localities where rodents

are a nuisance, broken glass has been incorporated in the earth of the lower 2 feet of wall. Cows are particularly fond of licking the bare earth of untreated walls; therefore the inside surfaces of stable walls, within reach of animals, should be coated with a wash of tar or cement. In the tropics, where white ants are a plague, carbolinium, arsenite of soda, or other ant preventive is generally mixed with the earth of the first course.

BLOCKS

The earth is sometimes rammed into molds to form blocks and then dried in the sun. The blocks are of various sizes but average about 18 by 12 by 9 inches and are used in the construction of exterior walls, columns, and 9-inch partitions. Figure 22⁷ illustrates a good type of mold used in making blocks 9 by 9 inches and 18 inches high. In actual construction blocks should be longer than high and as wide as the wall, unless its thickness would require a block too heavy to be easily handled. In such case the width should be one-half the wall thickness less one-half of the joint. The block should be made so that it may be laid with the laminations horizontal. The blocks can be bonded with lime or cement mortar or a thin mixture of the earth used in the blocks.

USE OF CONTRACTORS' IMPLEMENTS

Attempts have been made to adapt clay-mixing machines, pneumatic rammers, concrete block machines, cement guns, and similar equipment to pisé construction, but so far these have not been a success, with the possible exception of apparatus for spraying liquid coatings, especially tar. Labor-saving machines doubtless would be economical where much pisé work is to be done, but their cost hardly warrants their use in the relatively small amount of earth construction that an individual is likely to undertake.

CONCLUSION

Pisé de terre is not known to modern builders as are cob and adobe. The reason is not clear, for from all reports it is a method of construction with many advantages not possessed by the other two and in some respects is superior to frame and masonry. It was first employed in this country during the sixteenth century. The few early instances of its use failed to establish it, and now after war has strained the economic resources of the world low-cost construction is demanded and the merits of pisé de terre are remembered.

No permanent building material is cheaper, and when spare-time farm labor is employed very little cash outlay is required to erect durable structures, especially when the roof timber is cut from the farm wood lot and concrete made with local gravel is used for the floors.

The natives of the Southwestern States do not hesitate to build with adobe, but the kind of soil and the construction methods em-

⁷ Form for test blocks used by the California Experiment Station, Division of Agricultural Engineering, University of California.

ployed limit its use to the semiarid regions, whereas pisé de terre is adaptable to a wider range of territory.

The information contained in this bulletin was taken largely from the following publications published in this and foreign countries; most of these publications are not readily available:

Rural Economy, by S. W. Johnson, New York, 1808.

Journal of the Ministry of Agriculture, September, 1920, London.

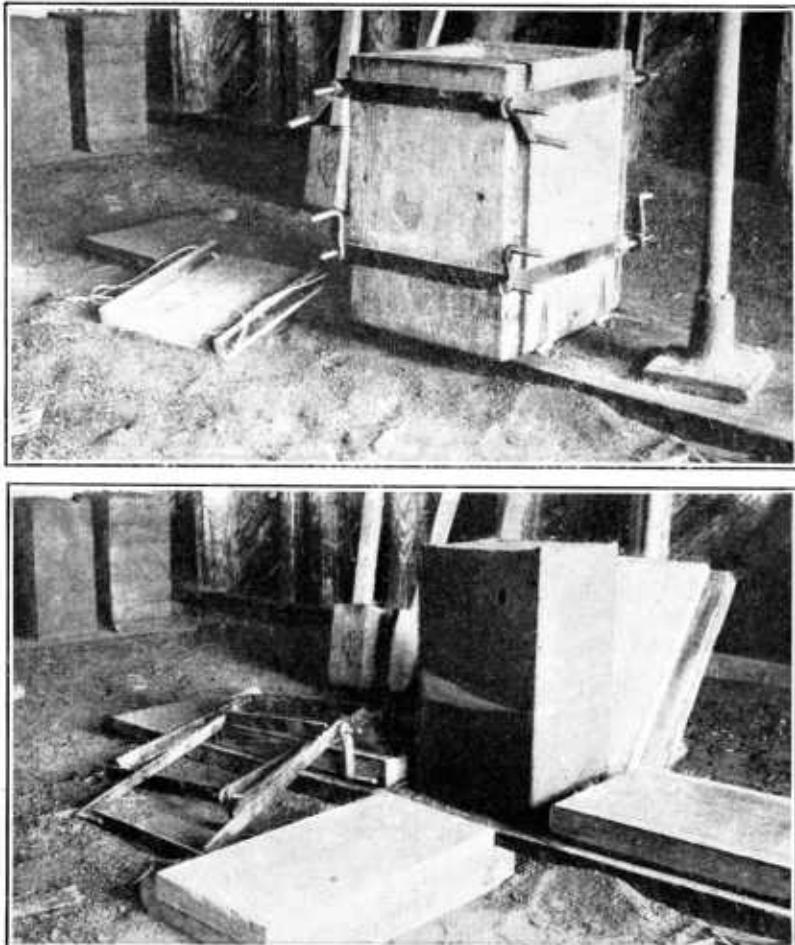


FIG. 22.—Block form

Special Report No. 5, Building Research Board, Department of Scientific and Industrial Research, London.

German Publications of Frederick Pour-Kattowitz, and E. Engel.

Experimental Cottages, by W. R. Jaggard, published by Department of Scientific and Industrial Research, London.

Other discussions of the subject that may be of interest to the reader will be found in—

The Cyclopediæ or Universal Dictionary of Arts, Science, and Literature, published in Philadelphia, 1818. (Article by Abraham Rees.)

Encyclopediæ Britannica, Ninth Edition, Vol. XIII.

Papers by P. B. Aird, Journal of the Department of Agriculture, Union of South Africa (1922).

Recent publications that are readily obtained are:

Modern Pisé Building, by Karl J. Ellington, Port Angeles, Wash.

Cottage Building in Cob, Pisé, Chalk, and Clay, by Clough Williams-Ellis, New York.

Rammed Earth Walls for Farm Buildings, by Ralph L. Patty and L. W. Minium, South Dakota Agricultural Experiment Station, Bull. 277, 1933.

The Relationship of Colloids in Soils to its Favorable Use in Pisé or Rammed Earth Walls. Ralph L. Patty, South Dakota Agricultural Experiment Station, Bull. 298, 1936.

Before attempting work on a large scale it would be wise to become familiar with the methods of manipulation by building a small garage or tool house after making the moisture and soil tests outlined on pages 4 and 5.